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MEMORANDUM REPORT NO. 1695

THE GENERATION AND PENETRATION CHARACTERISTICS OF HIGH DENSITY SHAPED CHARGE JETS (U)

by

J. M. Regan
G. H. Jonas

September 1965

In addition to security requirements which must be met, this document is subject to special export controls and each transmittal to foreign governments or foreign nationals may be made only with prior approval of U.S. Army Materiel Command, Attn: AMCMU-IS, Washington, D.C.

U. S. ARMY MATERIEL COMMAND
BALLISTIC RESEARCH LABORATORIES
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MEMORANDUM REPORT NO. 1695

SEPTEMBER 1965

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THE GENERATION AND PENETRATION CHARACTERISTICS OF HIGH DENSITY SHAPED CHARGE JETS (U)

J. M. Regan
G. H. Jonas

Terminal Ballistics Laboratory

Appendix by

Vernon Lamb and John Young

U.S. Bureau of Standards

RDT&E Project No. 1P014501A33E

A B E R D E E N   P R O V I N G   G R O U N D,   M A R Y L A N D

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MEMORANDUM REPORT NO. 1695

JRegan/GJonas/blw
Aberdeen Proving Ground, Md.
September 1965

THE GENERATION AND PENETRATION CHARACTERISTICS OF HIGH DENSITY SHAPED CHARGE JETS (U)

(CONFIDENTIAL) ABSTRACT

A high density (gold) shaped charge jet was successfully generated with a thin deposit of gold on the inner surface of a copper liner. The features of the jet and its ductility were observed by radiographs. The penetration characteristics of the jet into steel are analyzed. The increase in total depth of penetration (about 50 percent over copper) agrees excellently with theoretical predictions.

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TABLE OF CONTENTS

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(CONFIDENTIAL) INTRODUCTION

These experiments were completed to evaluate the feasibility of generating a high-density shaped-charge jet by using some practical material such as copper as the basic liner and electroplating a high-density metal on the inner surface. The inner layer of a shaped charge liner is the part that normally forms the jet during collapse so the substitution of a high-density metal for this inner layer should generate a high-density jet providing that the normal collapse configuration is not disturbed or destroyed by the presence of a bi-metallic liner.

Copper was selected as the base liner metal and gold was plated on the inner surface. Some of the jets produced were radiographed to observe their breakup characteristics and velocities, while others were measured for their penetration-time rates and depth of penetration.

These limited tests are considered successful. An identifiable gold jet was generated that penetrated as predicted by theory and the jet, at least in part, exhibited unusual ductility.

(CONFIDENTIAL) BACKGROUND FOR THE EXPERIMENTS

It was hypothesized that if a thin layer (< .020 inch) of high-density (> 15 g/cc) material could be deposited on the inner surface of a copper shaped-charge liner a jet of the high density material would be generated. If successful, it might prove to be a practical method for (a) producing long rods of high-density materials moving at ultra high velocities, (b) studying the penetration capabilities of high-density materials and (c) improving the penetration capabilities of shaped-charge warheads while avoiding increases in warhead weight.

The established density law[1*] for steady-state jets is

$$P = \sqrt{\frac{\rho_j}{\rho_t}}\, \ell \tag{1}$$

* *Superscript numbers refer to references which may be found on page 29.*

where P = total depth of penetration

ρ_j = density of the jet material

ρ_t = density of the material being penetrated by the jet, usually referred to as the target material

ℓ = length of the jet.

Equation (1) predicts, for example, that for two jets of a given length, ℓ, and densities, ρ_j, of 19.2 g/cc (gold) and 8.9 g/cc (copper) penetrating a given target material of density ρ_t, the former will penetrate to a depth approximately 50 percent greater than the latter. This estimate presumes that the velocities of both jets are greater than, say, 3000 meters per second so that the hydrodynamic model, from which the equation is derived, will apply.

Conventional shaped-charge jets contain a spectrum of velocities with the tip of the jet traveling faster than succeeding portions. Therefore, the jet stretches and its total penetration depends not only upon its density but also upon other factors such as the ductility and the velocity gradient. Eventually the ductility of the jet material is exceeded and the jet separates into a series of discrete particles. While the jet remains continuous the penetration velocity is related to the jet velocity and density at the stagnation point by the relation[1]

$$\frac{dp}{dt} = U = \frac{V_j}{1+\gamma} \tag{2}$$

where U = penetration velocity

V_j = velocity of the jet at the stagnation point of jet and target material

$\gamma = \sqrt{\dfrac{\rho_t}{\rho_j}}$.

Thus, if one has a measure of the penetration velocity, U, and the jet velocity, V_j, it is possible to detect a significant change in the density, ρ_j, of the jet material.

More sophisticated equations, however, have been developed[2,3] to cope with the penetration-time histories of shaped charge jets, thus:

$$P(t) = V_j^{o} t \left(\frac{t_o}{t}\right)^{\frac{\gamma}{\gamma+1}} - t_o V_j^{o}, \quad t_o \le t \le t_1 \tag{3}$$

$$P(t) = P(t_1) + \frac{t_1 (t - t_1) V_j(t_1)}{t\gamma + t_1}, \quad t_1 \le t \le T \tag{4}$$

where

T = total time of penetration, determined from the measured depth of penetration, (See Reference 3)

t_1 = time at which the jet breaks up and penetration by a continuous jet ceases

$P(t_1)$ = unique solution of $P(t)$ at time t_1

$V_j(t_1)$ = velocity of the leading particle of the jet at time t_1

V_j^{o} = velocity of the original tip of the jet

t_o = time at which the original jet tip arrives at the target.

Therefore if the shaped charge is detonated close to the target so that a sizeable portion of the jet is continuous as it penetrates then Equations (3) and (4) can be used to determine not only the density of the jet material but also the ductility. It is necessary only to measure the penetration time as a function of depth providing the penetration time behavior is sufficiently sensitive to V_j and ρ_j. Equation (2) can be rearranged to indicate the effect of a change in ρ_j, on a steady state jet thus

$$U = \frac{\rho_j^{1/2} V_j}{\rho_j^{1/2} + \rho_t^{1/2}} \ . \tag{5}$$

A few values of U are tabulated for a range of values of ρ_j and a constant V_j of 6.0 mm/μsec.

(CONFIDENTIAL) TABLE I (U)

ρ_j, g/cc	U, mm/μsec
9	3.1
12	3.3
14	3.4
16	3.5
19	3.7

Increasing the density from that of copper to that of gold increases the slope of the penetration-time curve significantly by a factor of about 20 percent. Therefore a change in density of this magnitude should be easily observed.

In these experiments the liners were designed to have the same sectional density. The inner surface of the copper liner was removed to a certain depth and the copper was replaced with an equal mass (not thickness) of gold. So it was reasonable to expect that the gold jet produced would have the same velocity spectrum as the copper jet and the penetration-time comparison would be valid.

Gold was selected because: (a) it has good plating properties that allow the construction of a liner with a very thin layer of high density material on the inner surface to generate the jet; (b) it has a density sufficiently high to make a significant change in the penetration-time data; and (c) it has a higher shock impedance than copper and therefore should not separate at the interface. It was felt that gold had a good likelihood to succeed in demonstrating a method of achieving a high-density jet by the use of laminated shaped-charge liners. It was not intended to recommend its use in general shaped-charge applications although there may be certain isolated situations where its use may be justified.

The penetration-time data are compiled in Table II, the jet tip velocity data are compiled in Table III, and the radiographs are compiled in Figures 2, 3, and 4.

One slug from a laminated liner was examined in cross section. The macrographs of these cross sections are compiled in Figure 5.

Profiles of the penetrations in mild steel are compiled in Table IV.

The velocities of the various elements of the jets from the Cu-Au laminate and the .088 inch copper liners were measured from the radiograph sequences. These velocities are compiled in Tables V and VI.

(CONFIDENTIAL) DISCUSSION OF RESULTS

Penetration-time Data

The penetration-time for all three liner designs were fitted with theoretical[2] curves using Equations (3) and (4). The data together with the theoretical curves are illustrated in Figure 6. After using a range of values it was found that the constants of V_j^o and t_1 that fit the data best were 6.20 mm/μsec, and 150 μsec for the Cu-Au, 6.05 mm/μsec and 105 μsec for the .088 inch Cu and 5.81 mm/μsec and 95 μsec for the .105 inch Cu liners respectively. The V_j^o and t_1 for the gold jet were significantly higher than those for the copper jet. Since the penetration rate, U, is dependent on V_j an additional curve was computed for a copper jet having a V_j^o of 6.20 mm/μsec and a t_1 of 150 μsec for comparison. This calculated curve is compared to the original curves for the gold and .088 inch copper jets in Figure 7. The increase in the rate of penetration of the copper jet is significant. But obviously the higher values of V_j^o and t_1 account for only a small part of the difference between the copper and gold curves.

The basic penetration model[1] and the later modification[2] that adapts the model to the shaped charge problem, agree excellently with the experimental data at this extreme density of jet. The slight adjustment in V_j and t_1 are well within the variability one might expect from shot to shot.

TABLE II

(CONFIDENTIAL) Penetration-Time Data (U)

Material Penetrated: Mild Steel BHN 100 (U)

Penetration inches	Depth cm	Cumulative Time, μsec PT289 Cu-Au (1)	PT 316 Cu-Au (2)	PT 319 Cu-Au (3)	PT 317 .088 Cu (4)	PT 318 .105 Cu (5)
1	2.54	5.95	6.00	5.70	6.20	6.30
2	5.08	13.15	16.55	13.15	17.25	18.30
3	7.62	20.80	27.05	21.15	27.65	29.75
4	10.16	29.60	45.40	29.75	39.55	41.50
5	12.70	38.90	62.05	38.90	52.20	54.40
6	15.24	48.45	156.50	48.40	67.30	68.90
7	17.78	58.60		58.75	81.80	84.35
8	20.32	68.80		69.80	98.00	105.55
9	22.86	79.95		81.05	116.30	127.95
10	25.40	91.70		92.20	137.45	152.65
11	27.94	103.40		104.55	164.70	186.65
12	30.48	115.90		117.15	192.30	226.30
13	33.02	130.20		130.15	237.35	279.90
14	35.56	145.05		143.45	289.75	
15	38.10	177.35		157.15		
16	40.64			172.10		
17	43.18			186.40		
18	45.72			202.45		

(1) Total penetration 15.9 inches, jet waver indicated in the last stages of penetration.

(2) Excessive jet waver evident in target plates

(3) Insufficient plate was prepared for the time record however the jet continued into some plates in the ground for a total penetration of 20.5 inches.

(4) Total penetration 14.75 inches.

(5) Total penetration 13.38 inches.

(CONFIDENTIAL) TABLE III

(CONFIDENTIAL) Jet Tip Velocity Measurements (U)

Rd.	Liner	Velocity, mm/μsec
PTX 318	Cu-Au	6.40
PTX 319	.088 Cu	6.05
PTX 320	.105 Cu	5.81*

*This value compares excellently with measurements made about 2 years ago for this same charge and liner design. The tip velocity then was 5.82 mm/μsec.

TABLE IV

(CONFIDENTIAL) Diameter of Hole at Various Depths (U)

Listed as Entrance and Exit Diameters in the 1.0 in. Mild Steel Plates In The Stack (U)

Units are inches

Plate No.	PT 289 (Cu-Au) Entrance	PT 289 (Cu-Au) Exit	PT 317 (.088 Cu) Entrance	PT 317 (.088 Cu) Exit	PT 318(.105 Cu) Entrance	PT 318(.105 Cu) Exit	PT 319 (Cu-Au) Entrance	PT 319 (Cu-Au) Exit
1	1.50	1.30	1.60	1.25	1.70	1.10	1.25	1.00
2	0.95	0.95	1.10	1.05	1.00	1.00	0.90	0.90
3	0.85	0.85	0.90	0.90	0.85	0.90	0.80	0.80
4	0.70	0.65	0.85	0.85	0.70	0.80	0.65	0.75
5	0.60	0.65	0.75	0.80	0.65	0.75	0.55	0.65
6	0.55	0.55	0.55	0.65	0.55	0.65	0.50	0.60
7	0.50	0.50	0.55	0.55	0.70	-*	0.50	0.55
8	0.45	0.50	0.50	-*	-	-	0.50	0.50
9	0.45	0.50	-	-	-	0.50	0.45	0.45
10	0.45	0.45	-	0.40	0.50	0.40	0.45	0.45
11	0.40	0.40	0.45	0.40	0.50	0.40	0.40	0.45
12	0.35	0.35	0.40	0.35	0.40	0.40	0.40	-*
13	0.40	0.40	0.35	0.35	0.45		-	0.40
14	0.30	0.35	0.35	0.60			0.35	-
15	0.30	0.45					-	0.35
16	0.60						0.35	0.35
17							0.30	0.35
18							0.35	0.40
19							0.35	0.40

*Slug lodged in plate, measurement not made.

TABLE V

(CONF) Velocities of Jet Particles from a Copper-Gold Laminate Liner Equivalent to a .088" Copper Liner (U)

Particle No.	V_1* mm/μsec	V_2 mm/μsec	Particle No.	V_1 mm/μsec	V_2 mm/μsec
1(Jet Tip)	6.30	6.22	29	4.75	4.57
2	6.20	6.18	30	4.65	4.48
3	6.15	6.13	31	4.62	4.44
4	6.12	6.07	32	4.52	4.35
5	6.08	6.00	33	**	4.26
6	6.02	5.95	34		4.19
7	5.95	5.89	35		4.13
8	5.90	5.80	36		3.97
9	5.85	5.75	37		3.92
10	5.82	5.73	38		3.88
11	5.78	5.73	39		3.79
12	5.78	5.71	40		3.66
13	5.72	5.66	41		3.63
14	5.68	5.58	42		3.57
15	5.60	-	43		3.48
16	5.52	5.40	44		3.43
17	5.45	5.31	45		3.34
18	5.40	5.24	46		3.26
19	5.32	5.20	47		3.23
20	5.30	5.17	48		3.19
21	5.18	5.06	49		3.12
22	5.15	5.02	50		3.10
23	5.10	4.93	51		3.19
24	5.08	4.91	52		3.01
25	5.02	4.86	53		2.92
26	4.98	4.82	54		2.88
27	4.92	4.77	55		2.81
28	4.85	4.66			

* V_1 = velocity determined from the first two of the sequence of three radiographs.

V_2 = velocity determined from the second two of the sequence of three radiographs.

**The first radiograph was too early to distinguish these particles.

TABLE VI

(CONFIDENTIAL) Velocities of Jet Particles from a Copper Liner 088" thick (U)

Particle No.	V_1* mm/μsec	V_2 mm/μsec	Particle No.	V_1 mm/μsec	V_2 mm/μsec
1(Jet Tip)	6.22	5.97	21	4.24	4.10
2	-	5.92	22	4.24	4.10
3	6.04	5.81	23	4.16	4.01
4	5.89	5.70	24	4.14	4.01
5	5.74	5.52	25	3.93	3.88
6	5.69	-	26	3.76	3.63
7	5.54	5.30	27	3.68	-
8	5.46	5.26	28	3.58	3.50
9	5.39	5.12	29	3.41	3.36
10	5.31	5.08	30	**	3.30
11	5.24	-	31		3.12
12	5.16	4.90	32		3.12
13	5.16	4.90	33		3.10
14	4.99	4.74	34		3.05
15	4.76	4.61	35		3.07
16	4.74	4.61	36		2.87
17	4.59	4.43	37		2.80
18	4.59	4.43	38		2.58
19	4.56	-			
20	4.44	4.28			

* V_1 = velocity determined from the first two of the sequence of three radiographs.

V_2 = velocity determined from the second two of the sequence of three radiographs.

**The first radiograph was too early to distinguish these particles.

The penetration-time curve for the gold jet (Figure 6) is the data from Rd. PT 319. Rounds PT 289 and PT 316 were not compared because the penetrations are inferior. With no intention of minimizing the undesirability of an inferior penetration these occurrences are considered of secondary importance for these experiments. It was intended here to observe the feasibility of generating a jet with a high density, low sound velocity material by depositing a small amount of the material on the inner surface of a liner of proven material. Having generated a bonafide jet by this method it was then intended to study its penetration characteristics and ductility. Now that a jet of deposited material has been clearly obtained it remains to study more closely the techniques of making the performance more consistent, and extend the techniques to the investigation of materials more practical than gold.

Radiographs

Lest the obvious be overlooked, it should first be noted that the copper-gold laminated liner design forms a bonafide shaped-charge jet with the same overall features as a jet from a solid copper liner. However certain differences in the characteristics of the copper and gold jets are clearly evident in the radiographs (Figures 2, 3, and 4).

The diameter of the gold jet is much smaller than the diameter of the jet from the equivalent (.088 inch thickness) copper liner. This is, at least partially, because at the stagnation point of the liner collapse, momentum must be conserved between the material going into the jet and slug. It requires a smaller volume of gold to provide a given mass. It should be recalled here that the two liner designs had the same sectional density, presumably the same collapse velocity, and therefore would enter the stagnation point with the same velocity. It is then reasonable that the partitioning of mass between the jet and slug will be the same for both jets.

There is evidence of a greater amount of ductile drawing in the gold jet. Although some ductile drawing takes place with the copper jet the pieces are typically "chunky" and many have jagged edges that indicate

brittle fracture. The gold jet in some parts has drawn down to very small (less than 1.0 mm) diameters before separating. The degree of ductility present in this jet is particularly evident in one section (Figure 8). This section is still continuous 180 μsec after formation. This degree of ductility is much greater than any observed in shaped charge jets heretofore for any material. It is, furthermore, evident that gold is far more ductile at the ultra high rates of strain present here than it is at laboratory rates[4] commonly used to measure elongations. Gold is normally less ductile than copper but the evidence in these experiments indicate it to be more ductile at these strain rates.

The tip velocity of the gold jet was measured from the radiographs at 6.30 mm/μsec. This value compares well with the electronic measurement of 6.40 mm/μsec.

The tip velocity of the jet from the equivalent (.088 inch) copper liner was measured from the radiographs at 6.22 mm/μsec. This value is somewhat higher than the electronic measurement (6.05 mm/μsec) but the agreement is good.

<u>Examination of the Slug</u>

A slug was recovered from one of the copper-gold liners. It was sectioned in three places and examined for the presence of gold at the core. The macrographs of the sectioned slug are illustrated in Figure 5.

There was evidence of gold at the center of the entire slug. In fact the macrographs show that there was an excessive amount of gold in two locations. It is not possible to correlate the locations of the macrographs with the original part of the parent liner because the slugs are seriously deformed and lengthened when they lodge in the target plate.

Macrograph "1" indicates that the apex either had excessive gold or did not contribute to the jet. Macrograph "2" indicates that about all of the gold went into the jet. Macrograph "3" indicates that somewhere near the base of the liner there was excessive gold.

It can be concluded from the macrographs that:

a. the layer of gold did not spall off during the collapse of the liner, and

b. there was sufficient gold to form the entire jet.

(CONFIDENTIAL) CONCLUSIONS

Shaped-charge liners can be constructed as laminates of dissimilar metals with the inner metal being used to form the jet.

The penetration of shaped-charge jets can be greatly increased, without warhead weight increases, by the use of a thin layer of high density (> 15 g/cc) material for the inner, jet producing, surface of the liner.

Gold exhibits superductility when subjected to ultra high rates of strain produced in the collapse and jet formation processes of shaped charges.

The hydrodynamic penetration model and its adaptation to shaped charge jets adequately predicts the penetration characteristics of hypervelocity jets up to densities of 19 g/cc.

J. M. REGAN G. H. JONAS

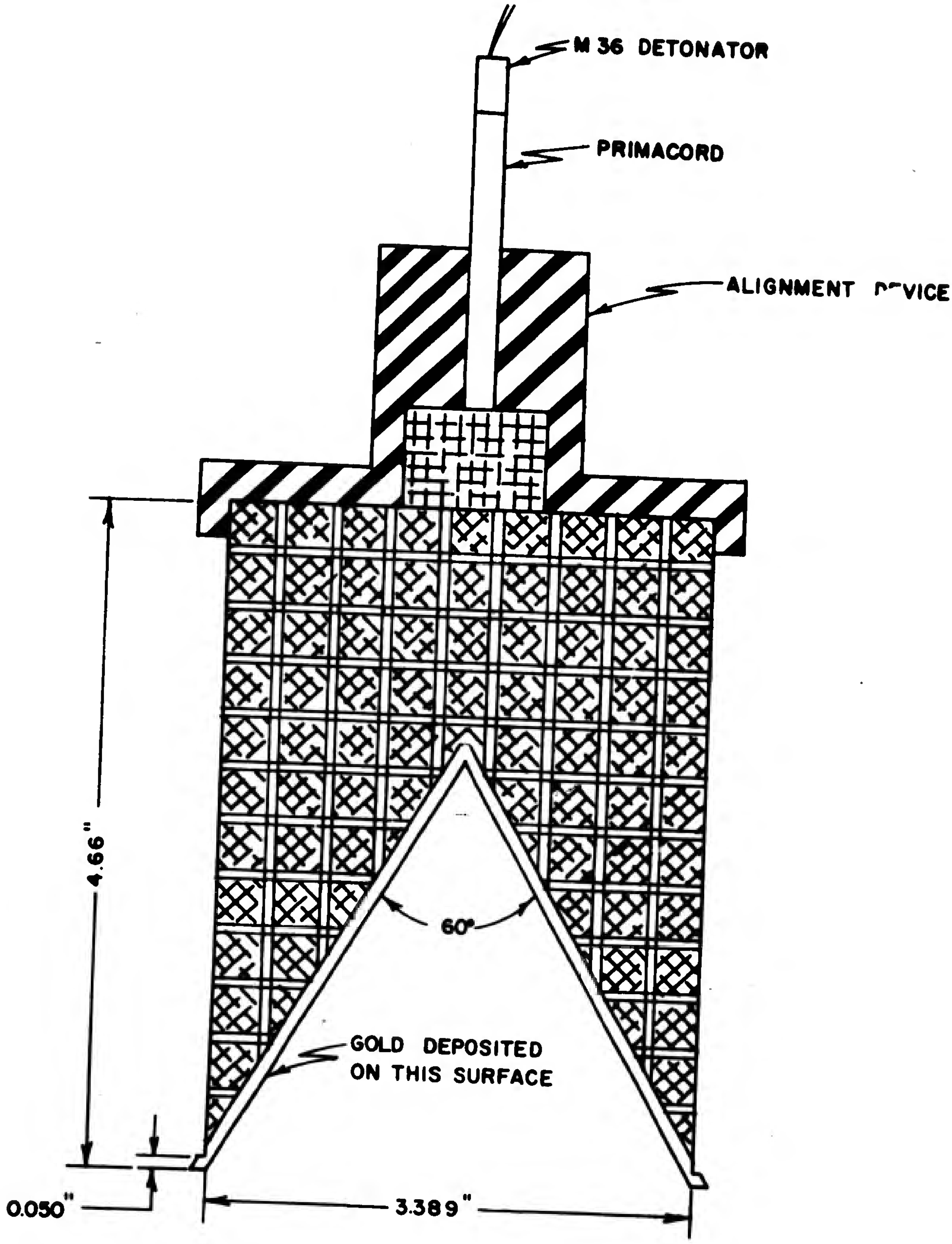

Figure 1. (CONFIDENTIAL) Charge design used to generate gold jets with a bi-metallic liner wall of copper and gold. (U)

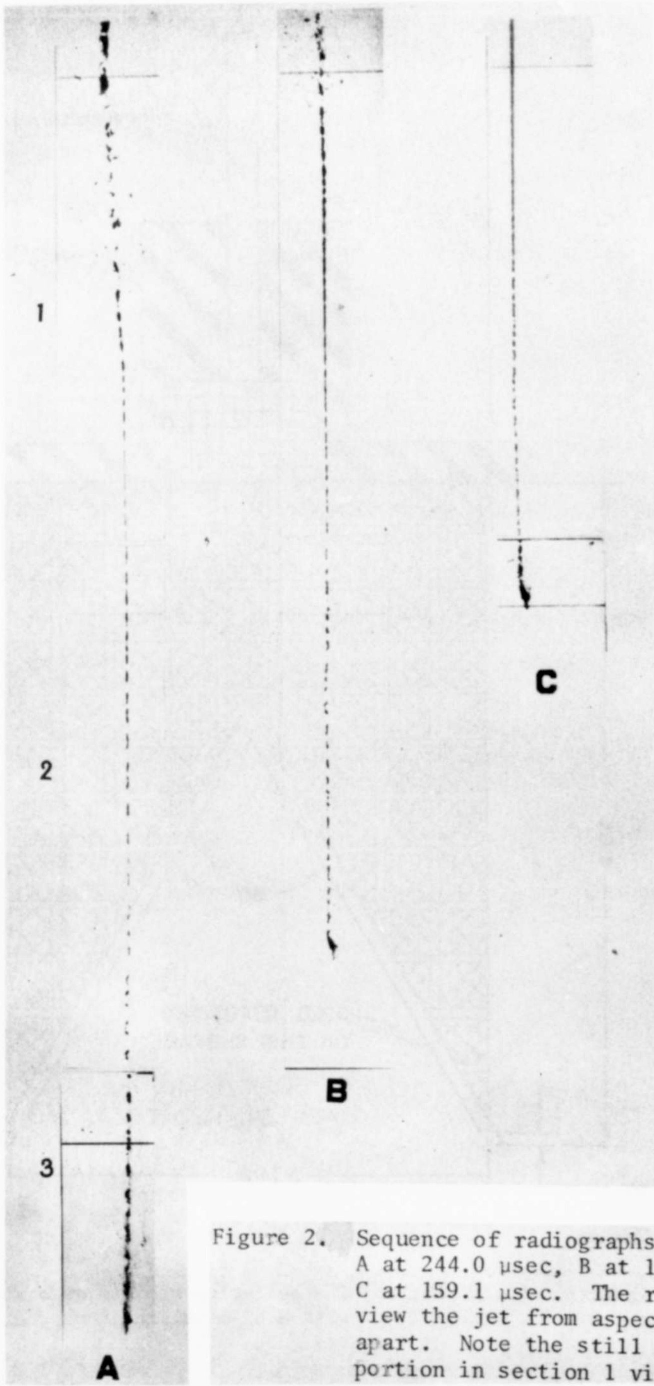

Figure 2. Sequence of radiographs of a gold jet, A at 244.0 μsec, B at 199.1 μsec and C at 159.1 μsec. The radiographs view the jet from aspects 45 degrees apart. Note the still continuous portion in section 1 view B.

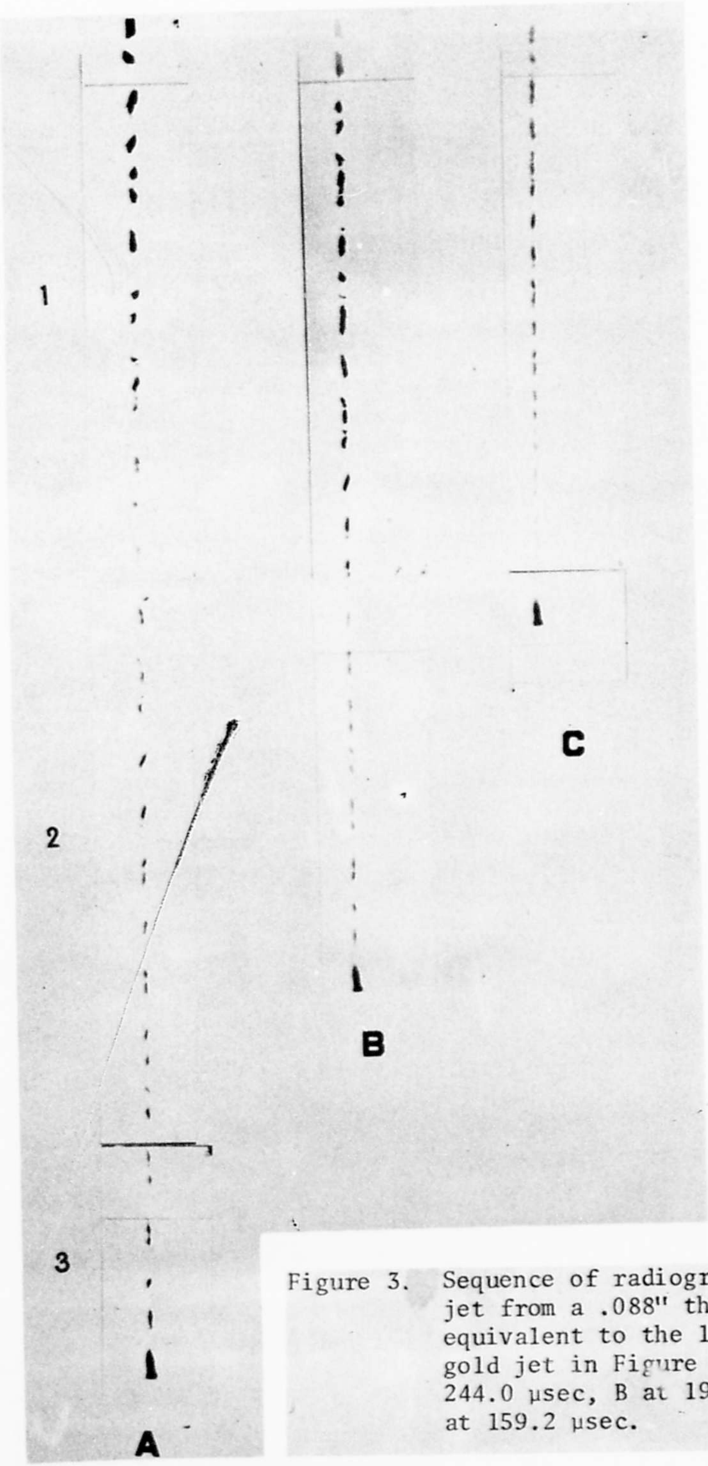

Figure 3. Sequence of radiographs of a copper jet from a .088" thick liner, equivalent to the liner used for the gold jet in Figure 2. View A is at 244.0 μsec, B at 199.1 μsec and C at 159.2 μsec.

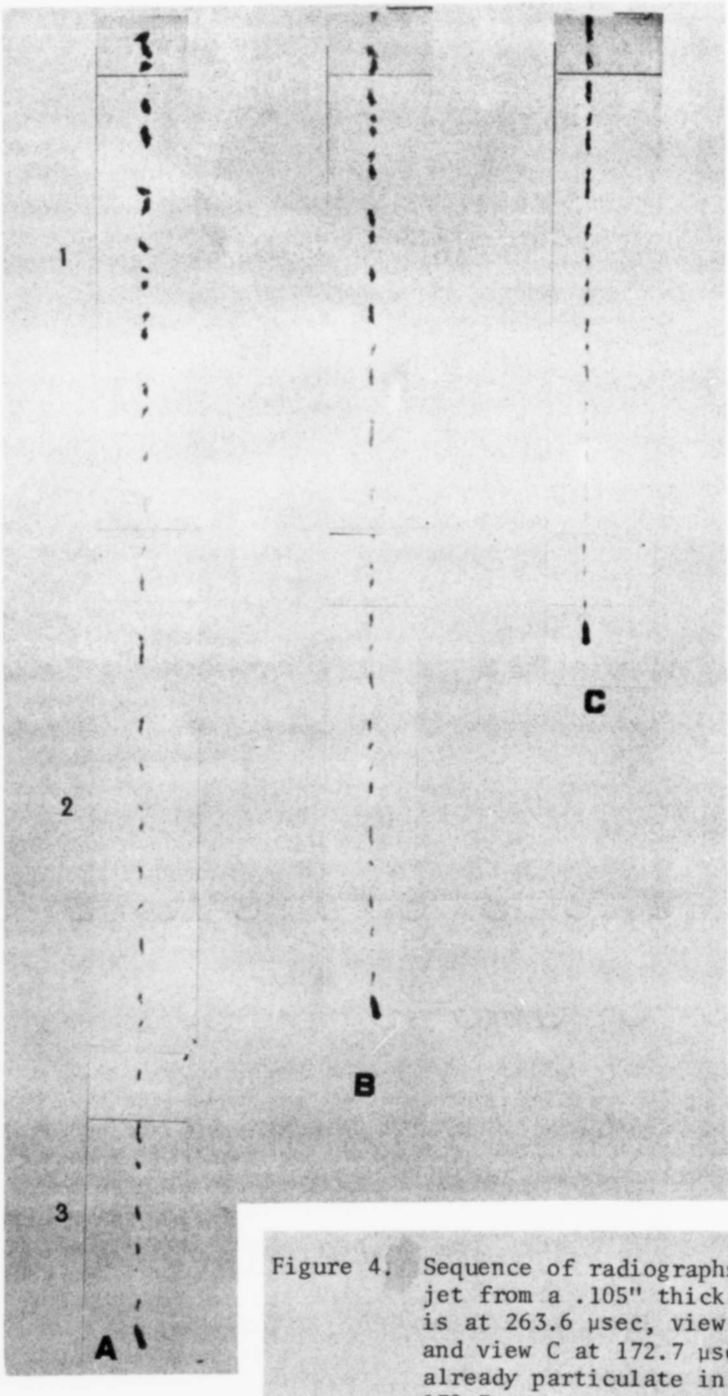

Figure 4. Sequence of radiographs of a copper jet from a .105" thick liner. View A is at 263.6 μsec, view B at 220.7 μsec and view C at 172.7 μsec. The jet is already particulate in view C at 172.7 μsec.

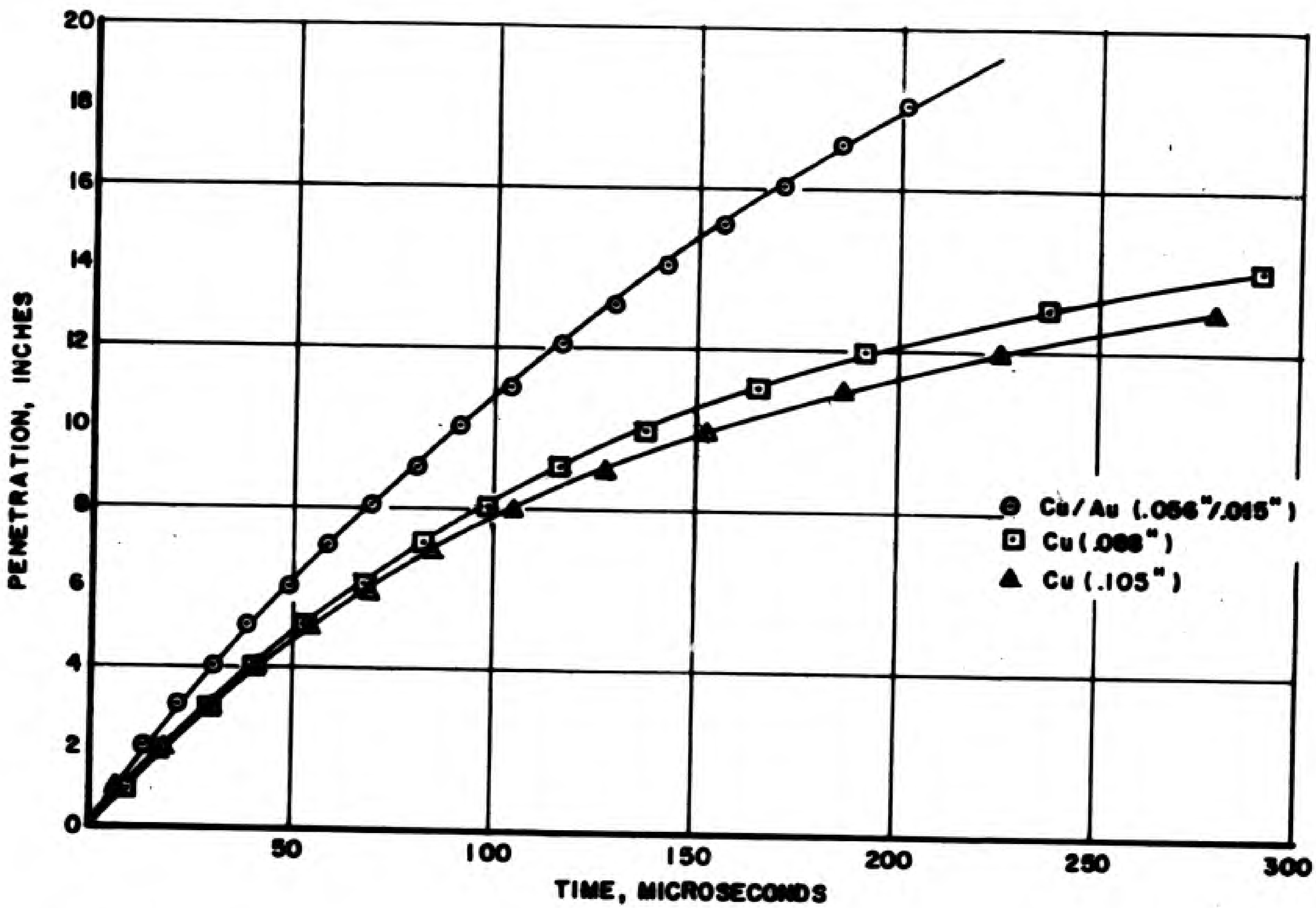

Figure 6. (CONFIDENTIAL) A comparison of the experimental penetration-time data and curves computed from theory. The points are experimental data and the smooth curves are computed. The .105" copper curve lies below the .088" copper curve because it has an overall lower velocity. (U)

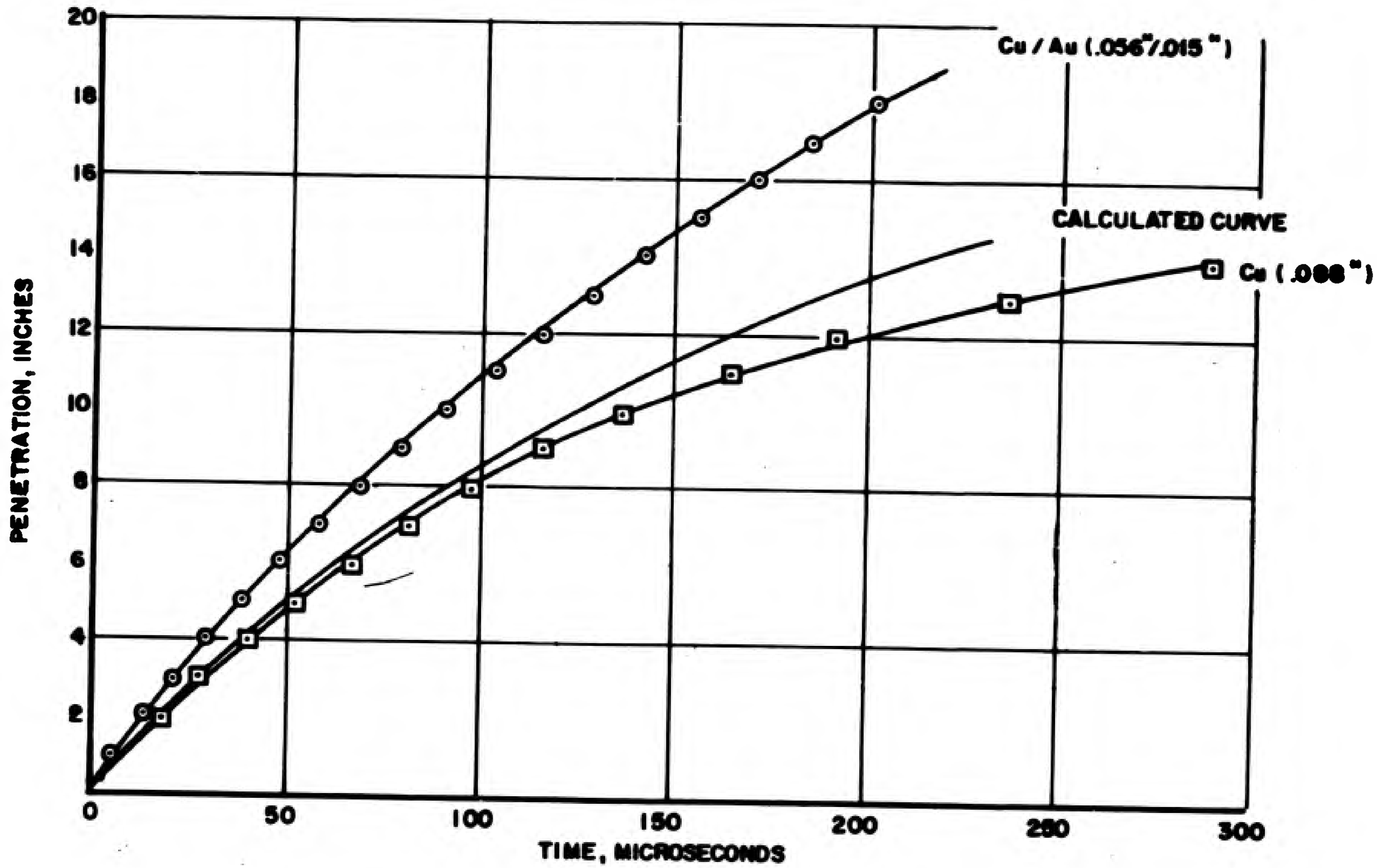

Figure 7. (CONFIDENTIAL) A comparison of the penetration time curve of the gold jet, its equivalent copper jet and a calculated curve in which the copper jet was attributed the same velocity and ductility as the gold jet. The difference between the calculated curve and the gold curve is attributed to the higher density of gold. (U)

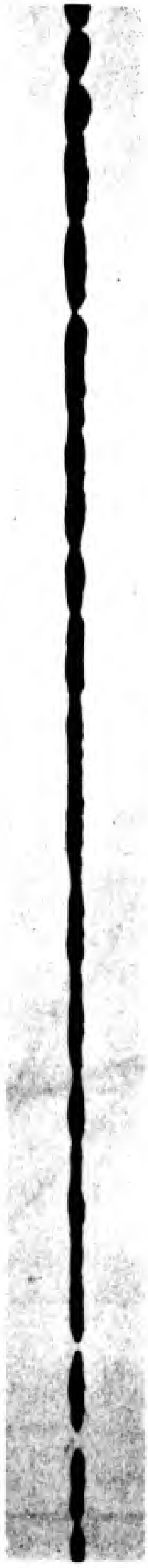

Figure 8. Section 1 view B, of Figure 2, enlarged to illustrate the continuity of the jet. In certain places the material has drawn down to a diameter of about 1.0 mm.

(UNCLASSIFIED)

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APPENDIX

(UNCLASSIFIED) HEAVY GOLD PLATING OF COPPER SHIELDS

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NATIONAL BUREAU OF STANDARDS REPORT

NBS PROJECT
3120460

NBS REPORT
Unnumbered

HEAVY GOLD PLATING OF COPPER SHIELDS

by

Vernon A. Lamb and John P. Young

Preliminary Report
April 15 - December 21, 1964

to

Ballistic Research Laboratories
Aberdeen Proving Ground, Maryland

U.S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

HEAVY GOLD PLATING OF COPPER SHIELDS

INTRODUCTION

NBS was requested on April 15, 1964, by Mr. Joseph M. Regan of APG, to electroplate the inside surfaces of ten (10) copper shields with gold 0.025 inch thick. The thickness requsted was later reduced to 0.015 inch. A minimum smoothing cut was to be taken on the inside surface prior to plating. The wall of the shield was then to be uniformly thinned by machining the outside to remove the same mass of copper as that of the gold to be applied on the inside. Five (5) shields plated to these specifications have been delivered to Mr. Regan.

PRELIMINARY INVESTIGATION

Introductory work included a search for and selection of a gold bath that would yield deposits of adequate softness and ductility, as well as sufficient smoothness at the required thickness. Operating procedures for obtaining good adhesion between the gold and copper and between the gold and gold were also developed as part of the preliminary investigation.

For a combined test of smoothness, ductility, and adhesion, specimens were made by plating about 0.015 inch thickness from a given bath onto a copper wire of 0.040 inch diameter. The deposit on the wire was bent until facture occurred. The amount of bending withstood before fracture indicated qualitatively the ductility of the gold deposit. The adhesion of the deposit to the copper and of a second layer of deposit to a previously gold-plated surface was checked by examining the fracture under magnification for separation between layers.

SELECTION OF THE GOLD BATH

The following types of bath were tested with the results summarized briefly:

1. "Industrial" or high gold-content cyanide bath

This bath contained gold (as $KAu(CN)_2$), 15 g/l; free KCN, 30 g/l; K_2CO_3, 60 g/l; K_2HPO_4, 30 g/l. At 60°C and 0.2 amp/dm^2 it yielded a soft pure deposit but was incapable of producing the desired thickness without development of excessive roughness.

2. Proprietary bath "Orosene 999"

This bath yielded a semi-bright and smooth deposit which was unsatisfactory because it was hard, brittle, and stressed. Stress-cracks formed in deposits thicker than 0.005 to 0.008 inch.

3. Proprietary bath "Industrial 24K"

This bath yielded a reasonably soft and ductile deposit but it was unsatisfactory because excessive roughness developed with increased thickness.

4. Proprietary bath "Orotemp 24"*

This bath gave the most promising deposits and was selected for use. This is a "neutral" cyanide bath containing a proprietary addition agent. It was found that the best deposits were obtained with concentration, temperature, and pH at the upper limits of the range specified by the proprietor. The operating conditions used are as follows: gold concentration (as metal), 20 g/l; temperature, 65 to 70°C; pH, 6.8 to 7.3; and current density, 0.5 amp/dm^2.

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* Sold by Technic, Inc., Providence, R. I.

Deposits remained smooth enough to permit continuous plating to thickness of 0.015 inch, though subsequent machining was required. Ductility was sufficient that deposits could be bent double twice before fracture. The grain structure is shown in Fig. 1.

MACHINING BEFORE PLATING

The copper shields furnished by APG were machined in the NBS Instrument Shop. The inside of the shield was machined just enough to true the surface. The outside was then machined to give a wall thickness of 0.056 ± 0.002 inch with the inside and outside surfaces concentric within 0.001 inch. Fig. 2 is a sketch of the machined shield. The inside surface had a finish after machining of 10 to 15 microinch A.A.

Preplating treatments

a. Preliminary cleaning and stopping off

Following machining, the shields were degreased in trichlorethane solvent and cleaned in a hot alkali cleaner. A connecting wire was placed around the outside of the shield one-half inch from the flange. The outside surface and flange were then insulated with stop-off lacquer which was baked at 90 C for one-half hour.

b. Electropolishing

The inside of the shield was electropolished for the purpose of smoothing and removing burrs from the machined surface. The process is carried out by making the shield anodic in an aqueous 70% phosphoric acid solution at room temperature, with a current density of 3 amp/dm^2. Although the surface was visually brightened by this treatment, the actual smoothness as indicated by profilometer measurement decreased from 10 to 15 microinch A.A. as machined, to 25 to 52 microinch A.A.

c. Final cleaning

Electropolishing leaves an anodic film on the copper that was removed by scrubbing with magnesium oxide and dipping in a 15% sodium cyanide solution. The shield was then transferred directly to the gold plating bath.

GOLD PLATING

The shield was supported in the plating vessel with the base about 1/2 inch above the surface of the solution. A hollow, conforming, stainless steel anode was placed in the shield with 1/4 inch distance between the anode and cathode surfaces. The plating solution was pumped from the bath through a filter, then into the hollow anode; it flowed through a hole in the tip of the anode into the shield, upward along the inside surface, and out over the flange into the plating vessel. The one gallon bath was maintained at about 65°C by heating on a hot plated. A lucite cover was placed over the vessel to minimize evaporation. At the current density of 0.5 amp/dm^2, gold is deposited at a rate of about 0.0007 inch per hour. The rate of depletion of the bath was sufficiently low that the shields could be plated during over-night runs. A plating time of about 24 hours was required to complete the initial deposit.

Some small pores were noticed in the gold deposits after machining. It is thought that these pores can be eliminated with improved plating conditions and more suitable fixtures now being made. The improved fixture will also result in a deposit of uniform thickness, thus requiring the removal of less gold when machining the plated surface to tolerance.

MACHINING THE GOLD DEPOSIT

A conical jig was made to align the shields in a lathe chuck by bearing on the outside surface of the shield. Any gold deposit that formed under the stop-off lacquer was removed from the outside and the shield fitted snugly into the jig. Light cuts were taken to minimize smearing of the soft gold. A heavy lard-oil cutting-tool lubricant and coolant was used to minimize tool-chatter and galling.

Overplating a second layer of gold

The machined gold-plated shield usually required a second layer of deposit to bring the thickness to the final required value. The procedure for over-plating was nearly the same as for initial plating, and included solvent degreasing, alkali cleaning, and stopping off as described above. The machined gold surface was then cleaned by scrubbing with pumice and soaking in a 15% sodium cyanide solution for 5 minutes. The final-plating and remachining to final tolerance were carried out by duplicating the corresponding steps described above. A sketch of a finished, gold-plated shield is shown in Fig. 3.

FUTURE WORK

Mr. Regan of APG has requested that the following additional shields be electroplated with 0.015 inch thickness of the indicated deposits:

With Gold Deposit

1. Ten (10) copper shields with 60° apex.
2. Ten (10) copper shields with 42° apex.

With Copper Deposit

1. Five (5) aluminum shields with 60° apex, standard copper.
2. Five (5) aluminum shields with 60° apex, copper with addition agent (UBAC).

With Silver Deposit

1. Five (5) copper shields with 60° apex.

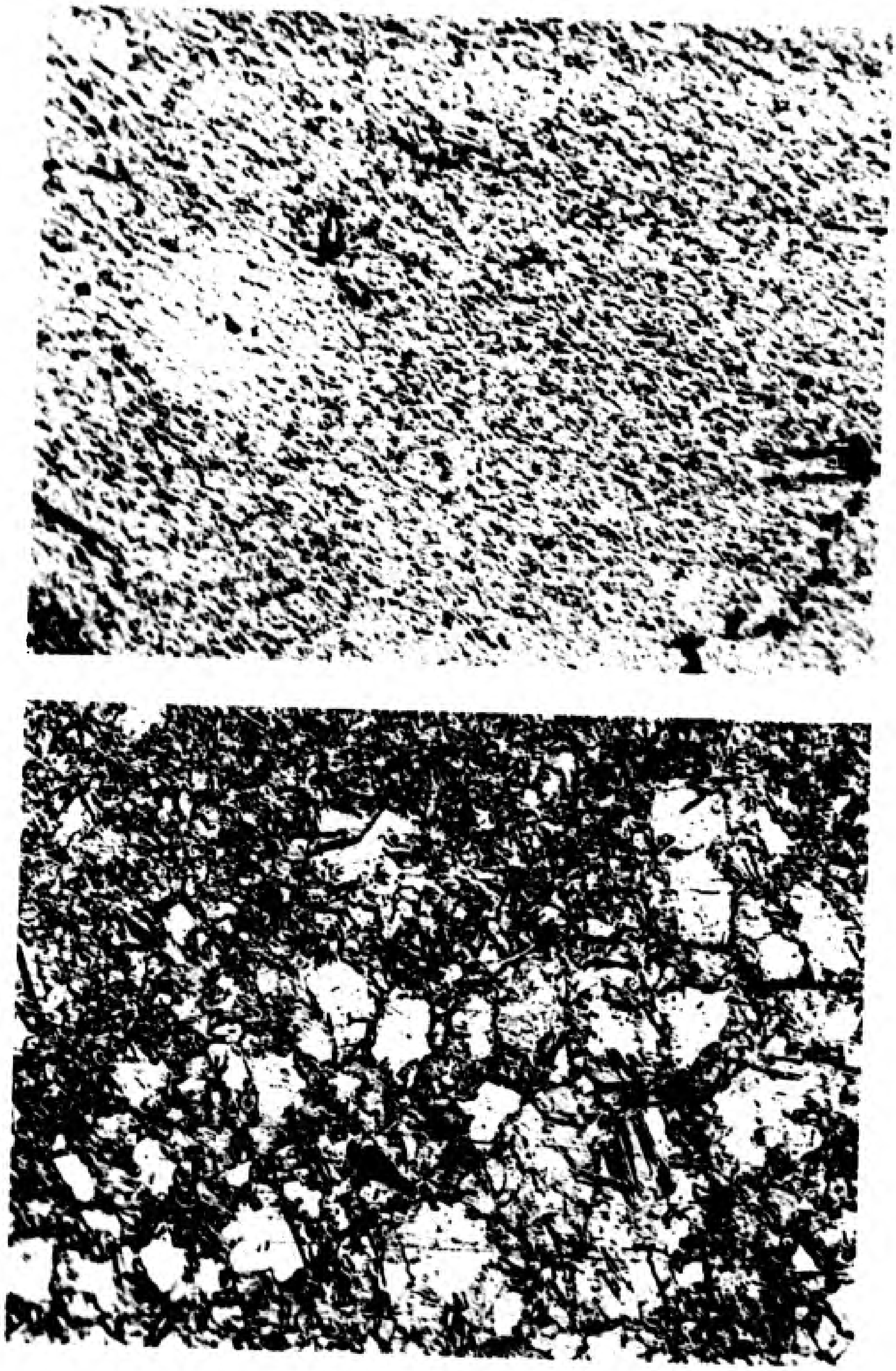

Figure 1. Microstructure of gold deposit at start of deposition (top) and near end of deposit 0.015 inch thick. Electrolytic etch in 5% KCN. X 500

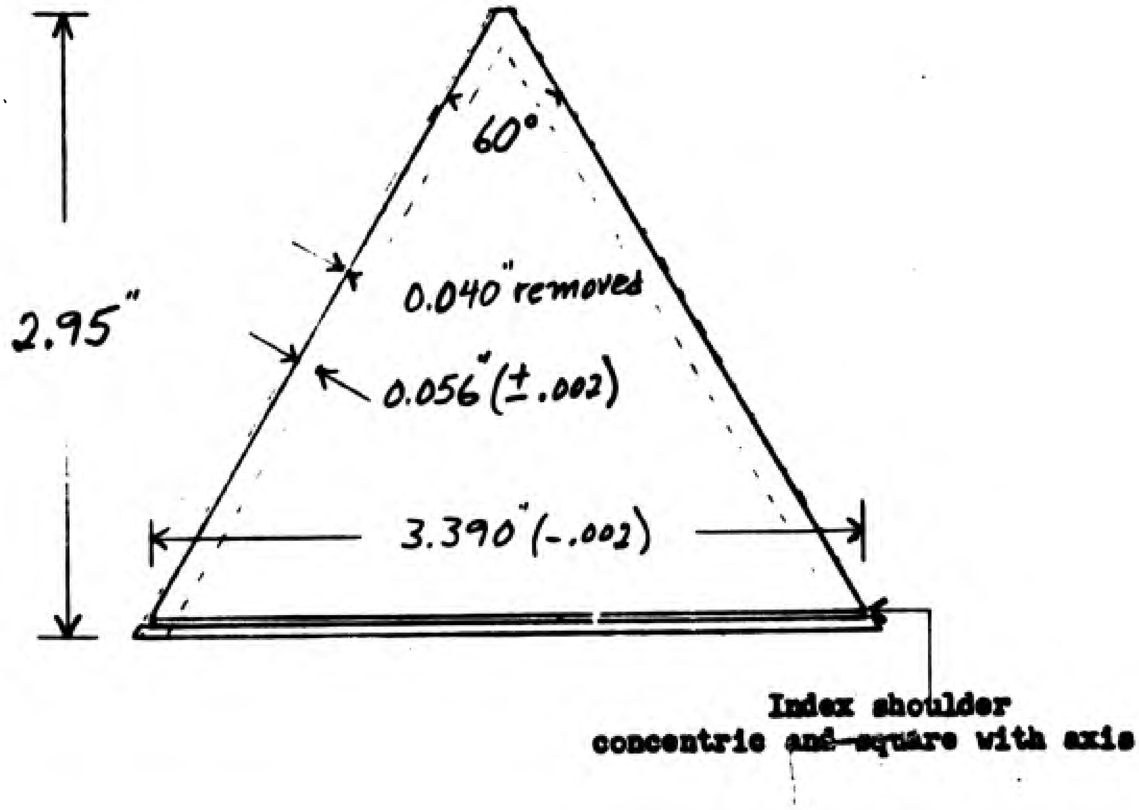

Figure 2. Copper shield as machined before gold plating

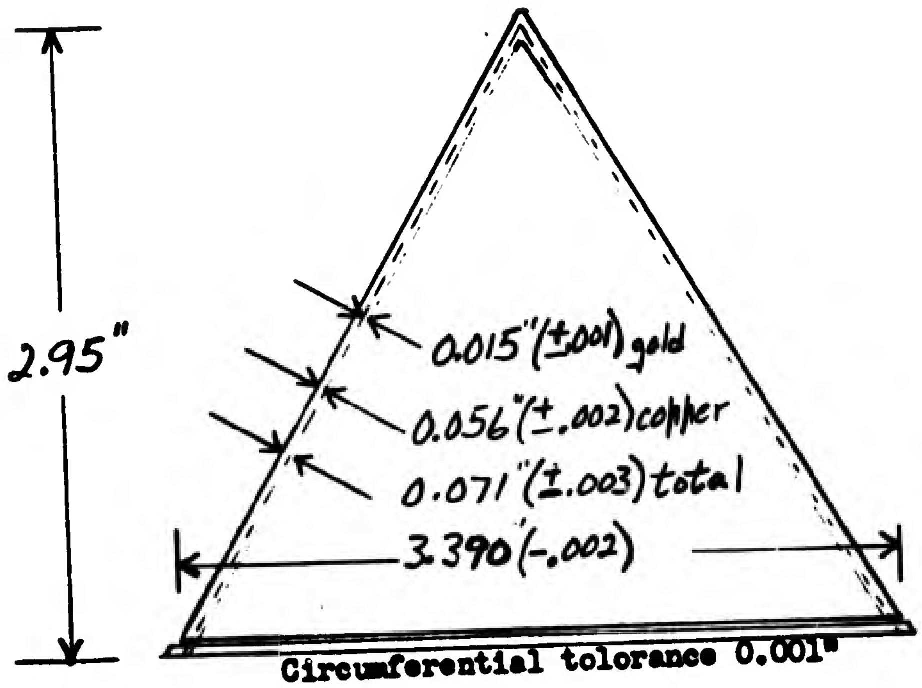

Figure 3. Gold plated shield

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A high density jet was successfully generated. The penetration characteristics of the jet into steel are analyzed. (U)

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